Technical Note

Quantitative Arthroscopic Assessment of Articular Cartilage Quality by Means of Cartilage Electromechanical Properties

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Abstract: Arthroscopic surgery has grown rapidly in recent decades. Despite accurately diagnosed clinical cases, the previous pain is retained in some patients after the operation, even though no visible chondral lesions are found during the procedure. A minimally invasive arthroscopic method of measuring articular cartilage electromechanical properties enables rapid and reliable intraoperative articular cartilage quality evaluation.

Articular cartilage defects remain a significant problem for the physically active population. The incidental findings of chondral or osteochondral lesions of varying severity in 63% of knee diagnostic arthroscopic surgical procedures present a great challenge to orthopaedic surgeons and patients.[1] Despite the well-established surgical techniques for cartilage repair, unbiased diagnostics of these lesions are scarce, especially when the cartilage has no visible deterioration. An inadequate diagnosis might interfere with successful postoperative management and a good clinical outcome.

Codesido et al.[2] evaluated causes of repeat knee arthroscopy and determined it was mostly performed because of nontraumatic continuous pain.[3] The study did not find a negative impact on clinical outcome after cartilage defects were left untreated; however, a tendency for a deterioration of clinical results with a longer follow-up time was noted. Therefore, there is a need for more precise and objective diagnostic methods to assess the quality of healthy-looking and repaired cartilage.

Recently, a minimally invasive method to evaluate articular cartilage quality by measuring its electromechanical properties has been developed. A handheld medical device, Arthro-BST (Biomomentum, Laval, Quebec, Canada), enables registration of electromechanical activity of articular cartilage during arthroscopic procedures.[4,5] The instrument measures compression-induced streaming potentials of articular cartilage and calculates the quantitative parameter (QP) reflecting cartilage electromechanical properties. QP, expressed in arbitrary units, is related to the number of microelectrodes, located on a small spherical indenter at the end of a sterile disposable tip, in contact with cartilage, when the sum of the cartilage's streaming potentials reaches 100 mV. During compression, positive mobile ions in the interstitial fluid are displaced relative to the fixed negatively charged proteoglycan molecules, which are entrapped in the collagen network. A higher QP value indicates weak electromechanical properties and inferior quality of the cartilage, represented by a degraded collagen network and a loss of proteoglycans, whereas a very low QP value indicates abnormally thin cartilage.[4] QP's correlation with histologic scores, biomechanical parameters, chondrocyte viability, and apoptosis has been shown, suggesting that this device enables rapid and reliable evaluation of articular cartilage properties before and after cartilage repair procedures.[4,6]

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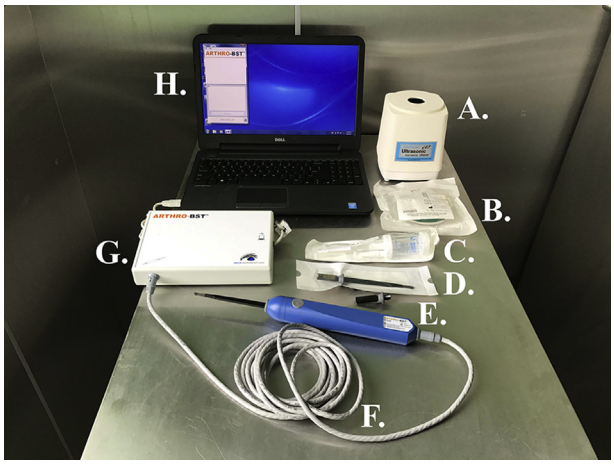

Fig 1. Complete set of cartilage measurement devices: ultrasonic cleaner bath (A), sterile camera drape (B), sterile plastic container (C), sterile disposable tip (D), handle with inserted demonstration tip (E), cable (F), electrical isolation box (G), and laptop computer (H).

The Arthro-BST device has been successfully used for the evaluation of articular cartilage in the goat knee after autologous and allogeneic osteochondral transplantation.[6] We present a video of a clinical case in which this technique has been adapted to evaluate human articular cartilage after osteochondral allograft transplantation during second-look arthroscopy (Video 1). These results are currently under evaluation.

Technique

Preparation of Device

The isoelectric box runs on 2 AA batteries with a universal serial bus connection to a laptop computer. A cable connects the handle of the tip to the computer, which is plugged into the electrical outlet and turned on.

Sterile Preparation of Tip and Approach

A surgical technician fills a sterile container with 30 mL of sterile saline solution and places the container into an ultrasonic cleaner bath (Cole-Parmer, Vernon Hills, IL) partially filled with water. The ultrasonic cleaner bath must be turned on. The technician then opens the packaging of the sterile tip and drops the sterile tip on the surgical instrument tray. The tip is inserted by a scrub nurse, and the handle connected to the electrical isolation box through the cable is securely sealed with an adhesive strip and cover. The complete set of equipment is depicted in Figure 1.

Patient Preparation

The patient is positioned supine, and standard anesthesia is initiated. The operative field is prepared according to standard aseptic procedures, including application of disinfectant and sterile blankets.

The knee joint should be well inflated with physiological saline solution. Arthroscopic examination is initiated through standard 6-mm medial and lateral parapatellar portals that should be placed accurately to facilitate access to the cartilage regions of interest. Additional portals can be used to approach more specific cartilage regions. The same portals are used for the introduction of the tip. Intra-articular macroscopic observation of articular cartilage lesions and treated areas is performed (Fig 2).

Measurements

Equilibration of the microelectrodes must be performed before the measurements. The end of the tip must be fully immersed for 5 to 10 seconds in a container with sterile saline solution in the ultrasonic

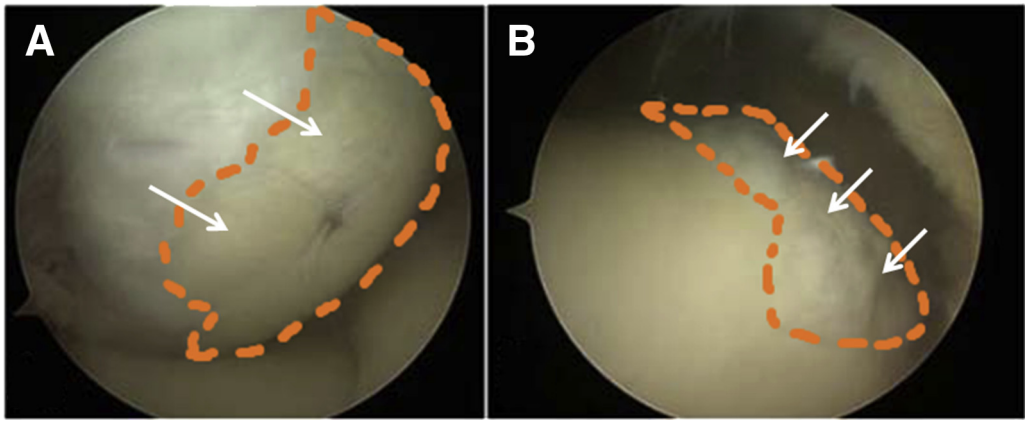

Fig 2. Arthroscopic images of cartilage repair site 4 years after osteochondral autograft transplantation in medial femoral condyle of right knee. The cartilage donor site of the harvested autograft is filled with fibrocartilaginous tissue. The patient is in the supine position with the lateral portal used for imaging and the medial portal for manipulation. The area marked by the dashed lines and the arrows show the autograft transplantation site in the medial femoral condyle (A) and the osteochondral plug harvest site in the outer ridge of the lateral femoral condyle (B).

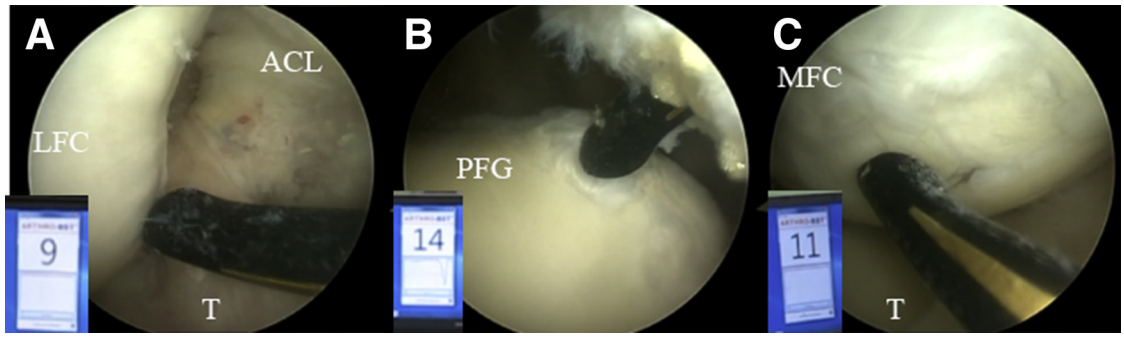

Fig 3. Arthroscopic images of Arthro-BST tip in contact with cartilage surface in lateral femoral condyle (LFC) (A), patellofemoral groove (PFG) (B), and medial femoral condyle (MFC) (C). One should note the tip placement perpendicular to the cartilage surface. The quantitative parameter (QP) value of healthy-appearing cartilage in the LFC was 9 (A), whereas the QP value of repaired cartilage at the donor site was 14 (B), indicating inferior cartilage quality. The QP value at the autograft transplantation site in the MFC was 11 (C), indicating good cartilage quality. (ACL, anterior cruciate ligament; T, tibia.)

cleaner bath. When the measurement software displays a straight line on the computer screen, the device is ready. The tip is inserted into the joint through standard arthroscopic portals according to the lesion location. QP measurements are performed at the center of the transplanted graft. The surgeon must touch and gently compress the cartilage surface with the tip in the area of interest. Because of the hemispherical shape of the tip, the microelectrodes are set on the surface of the hemisphere but not on the edges. During compression, the tip is positioned so that the cartilage is in contact with the microelectrodes on the spherical surface of the tip, as seen through the arthroscopic monitor. After compression on the cartilage surface, the software instantly displays a sudden drop and rise of the measuring line due to the evoked streaming potential. At this moment, the surgical technician must press the "process" button to register measurement and calculate QP. When the tip is in the right position, the QP value is displayed on the laptop screen. The measurements are repeated several times to obtain the median value (Fig 3). If the software fails to calculate the result because of the wrong tip position, an error message is displayed and the measurement must be repeated. Pearls and pitfalls of the measurements using the Arthro-BST device are described in Table 1.

To validate the procedure in a clinical setting, we analyzed patients undergoing a diagnostic arthroscopic procedure with normal magnetic resonance imaging data and macroscopically intact articular surfaces. Reference QP values measured for the healthy human knee articular cartilage ($n = 7$) were 14.29 ± 4.82 and 14.86 ± 3.93 for the medial and lateral femoral condyles, respectively, and 18.9 ± 3.65 and 21.4 ± 8.04 for the medial and lateral tibial condyles, respectively. In addition, QP measurements in the patellofemoral groove and patella were 14.57 ± 1.45 and 20.7 ± 4.46, respectively.

Discussion

Articular cartilage lesions of varying severity are becoming increasingly prevalent as a result of increased physical activity and improved diagnostics. In addition to large osteochondral lesions, cartilage areas with little to no visible deterioration are being increasingly diagnosed, despite the inferior predictability of imaging techniques for less advanced lesions.[7,8] Current methods of evaluation are limited to diagnostic imaging techniques, macroscopic evaluation, and arthroscopic hook probing. Similarly, cartilage repair procedures, which might result in hyaline-like tissue, are often evaluated by macroscopic scoring systems and quantitative magnetic resonance imaging.[8-10] However, clinical correlation and prediction of repair procedure outcome are yet to be determined.[11] This has prompted the need for a reliable objective method to evaluate the quality of cartilage tissue.

Electromechanical assessment has been proposed as a minimally invasive method to evaluate the mechanical properties and severity of degeneration for knee articular cartilage.[12] QP values obtained by a handheld arthroscopic device, Arthro-BST, showed significant

Table 1. Pearls and Pitfalls of Electromechanical Measurement Using Arthro-BST Device

Pearls
Additional portals can help with accurate tip placement within inconvenient parts of the cartilage.
The tip should gently press the cartilage surface of interest followed by a quick release to obtain a numerical value.
Correct tip placement perpendicular to the cartilage surface is confirmed by a steep decline in the streaming potential line on the computer screen.
Pitfalls
When the tip is released before the full decline of the streaming potential line, a measurement is not registered.
Different numerical values might be recorded with even slight movements in the same cartilage area when positioning the tip.

Table 2. Advantages and Limitations of Electromechanical Measurement Using Arthro-BST Device

Advantages
Quick intraoperative measurement
Rational perspective on histologic, biomechanical, and biochemical cartilage parameters (i.e., qualitative value of cartilage) provided by technique
Prognostic value for postoperative care
Disadvantages
Necessity for technical assistance to obtain measurement values
Learning curve with handling of device to obtain consistent and reliable results

correlation with conventional methods for objective cartilage quality determination, such as histologic assessment and biochemical analysis. QP measurements have been shown to provide insight into the cellular viability of osteochondral grafts in vitro, thus highlighting their use in graft quality determination before implantation in cartilage repair procedures.[13,14] Application of the device at follow-up after cartilage repair procedures is of immense value because it is less invasive than biopsy methods for tissue quality analysis. It has recently been shown that electromechanical assessment of cartilage quality after implantation of bilayer constructs was comparable with evaluation by conventional destructive methods in an in vivo sheep model.[15] Similarly, measurement of cartilage electromechanical properties during routine arthroscopic procedures can help to evaluate the tissue quality before major macroscopic lesions appear. Advantages and limitations of the described technique are discussed in Table 2. Hereby, a map of the articular cartilage surface area for the extent of cartilage degeneration could be determined. Subsequently, a personal postoperative rehabilitation protocol needs to be adjusted to improve the clinical outcome of the patient.

References

1. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: A review of 31,516 knee arthroscopies. *Arthroscopy* 1997;13:456-460.
2. Codesido P, Silberberg-Muiño JM, Leyes-Vence M. Incidence and causes of repeat knee arthroscopy. *Orthop Proc* 2009;91-B:321 (suppl II).
3. Magnussen RA, Verlage M, Flanigan DC, Kaeding CC, Spindler KP. Patient-reported outcomes and their predictors at minimum 10 years after anterior cruciate ligament reconstruction: A systematic review of prospectively collected data. *Orthop J Sports Med* 2015;3. 2325967115573706.
4. Sim S, Chevrier A, Garon M, et al. Non-destructive electromechanical assessment (Arthro-BST) of human articular cartilage correlates with histological scores and biomechanical properties. *Osteoarthritis Cartilage* 2014;22:1926-1935.
5. Sim S, Chevrier A, Garon M, et al. Electromechanical probe and automated indentation maps are sensitive techniques in assessing early degenerated human articular cartilage. *J Orthop Res* 2017;35:858-867.
6. Mickevicius T, Pockevicius A, Kucinskas A, et al. Impact of storage conditions on electromechanical, histological and histochemical properties of osteochondral allografts. *BMC Musculoskelet Disord* 2015;16:314.
7. von Engelhardt LV, Kraft CN, Pennekamp PH, Schild HH, Schmitz A, von Falkenhausen M. The evaluation of articular cartilage lesions of the knee with a 3-Tesla magnet. *Arthroscopy* 2007;23:496-502.
8. Higa K, Kitamura N, Goto K, et al. Effects of osteochondral defect size on cartilage regeneration using a double-network hydrogel. *BMC Musculoskelet Disord* 2017;18:210.
9. Guermazi A, Roemer FW, Alizai H, et al. State of the art: MR imaging after knee cartilage repair surgery. *Radiology* 2015;277:23-43.
10. Crema MD, Roemer FW, Marra MD, et al. Articular cartilage in the knee: Current MR imaging techniques and applications in clinical practice and research. *Radiographics* 2011;31:37-61.
11. Jungmann PM, Baum T, Bauer JS, et al. Cartilage repair surgery: Outcome evaluation by using noninvasive cartilage biomarkers based on quantitative MRI techniques? *Biomed Res Int* 2014;2014:840170.
12. Abedian R, Willbold E, Becher C, Hurschler C. In vitro electro-mechanical characterization of human knee articular cartilage of different degeneration levels: A comparison with ICRS and Mankin scores. *J Biomech* 2013;46:1328-1334.
13. Garrity JT, Stoker AM, Sims HJ, Cook JL. Improved osteochondral allograft preservation using serum-free media at body temperature. *Am J Sports Med* 2012;40:2542-2548.
14. Pallante AL, Chen AC, Ball ST, et al. The in vivo performance of osteochondral allografts in the goat is diminished with extended storage and decreased cartilage cellularity. *Am J Sports Med* 2012;40:1814-1823.
15. Schagemann JC, Rudert N, Taylor ME, et al. Bilayer implants: Electromechanical assessment of regenerated articular cartilage in a sheep model. *Cartilage* 2016;7:346-360.